

**MESHNETWORKS, INC.
INVENTION DISCLOSURE FORM**

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Invention Record No. D-044	Date October 10, 2001
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INVENTION RECORD

Title of Invention:

Complex Adaptive Routing System *and method*

Inventor(s) (See Instruction 1.) Note: Instructions referred to by number are printed on the Instruction Page.

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DESCRIPTION OF SUBJECT

Complex Adaptive Routing System

Traditional routing systems use a designed infrastructure which provides efficient routes for data to flow from a source to a destination. A packet of data has source and destination addresses, and the infrastructure chooses the route and transports the packet from the source to the destination. An analogy of this type of routing system is a package delivery service.

A complex adaptive system is formed by a large number of individual agents, with unique strategies, which operate as a group in a physical environment, and pass forward successful

strategies by direct communication and by reproduction of the most successful agents, with trait recombinations and a very small percentage of mutations. An analogy of this type of system is a bee hive. Many individual bees follow strategies which serve the entire colony, and which also serve the individual. Successful strategies are communicated to other bees. The entire colony has an emergent behavior which is different from the behavior of individuals. Successes are rewarded, and new strategies are discovered and tested.

The advantages of a complex adaptive routing system over an designed infrastructure system are the ability of the system to adapt quickly to changing conditions, and to discover and employ new and efficient strategies, without the requirement that the strategy be pre-designed into the infrastructure.

The agents of a complex adaptive routing system are the packets and the nodes. The primary agents are the packets, which interact with the routing information on the nodes to determine the next hop of their choice based on their strategy. (Other agents may be added to this system.) When a packet arrives at a node, the packet's node history and strategy are extracted and provided as input to an agent program which is executed in the node to allow the packet to determine the next destination that is best according to the packet's strategy. The nodes provide the computer processing and data storage infrastructure for the packet agents. The latest routing information in the node is made available to the agent program. Information from the packet and the agent program is provided to the node in the form of updates for the node's routing tables. Newly discovered routes are transmitted to the relevant nodes using this mechanism. The packets contain a memory of the nodes they have visited. They also have a memory that stores their strategy, which may include the desired route. The packet agents use this information while employing their strategies and discovering new strategies. Strategies are associated with goals. For example, to traverse from point A to point B, the best strategy contains the best route to B from A. To traverse back from B to A, the goal is different, and the strategy is different. The knowledge of the best strategy from A to B can be used in the discovery of the best strategy from B to A, however the strategy of using the reverse of the best route from A to B is not necessarily always the best strategy. If there is an fiber link available from B to A, but only in that direction, and at a much higher speed than the ethernet from A to B, then the discovery of the fiber link route will outperform a competing strategy of the reverse ethernet route from B to A, and will be assigned credit for the better strategy. This credit will allow the most fit strategy to reproduce during rule discovery. This allows real-time feedback from the physical environment to be considered in the dynamic discovery of new and more efficient strategies.

Nodes can store information about the packet agents that have traversed the node, the strategies they used, and the destinations they selected. For example, if 99% of the packets in the last minute selected next hop A to get to Dest1, and 1% chose B, then a packet agent can choose A or B as locally discovered routes, and can qualify the choice based on factors such as link reliability, speed, or popularity.

Strategies are represented by simple character strings which interact with functions in the agent program. The functions are detectors and effectors. Detectors are the senses of the agent, and effectors are the means to turn a symbolic strategy into an action. In a sense, the destination address of an ordinary packet is a simple strategy, which translates as "please send me to the

address x.x.x.x". A more advanced strategy might be represented by "DestHost A B C ; D ; *", which translates as "My destination is DestHost, and I would like to be routed via known paths to DestHost A, B, or C, or if those fail use known route D, and if that fails use the locally discovered paths." An alternative strategy might try the locally discovered paths first, a risky but possibly rewarding behavior. An explicit strategy can carry an advertisement of a known path with a unique identifier to the nodes: "Path P321 To DestHost 144 153 12 72 DestHost". This explicit strategy becomes known as the symbolic strategy "P321", which facilitates the exchange of knowledge in the development of new strategies.

Successful strategies are rated on their performance. For example, strategies with the fewest number of hops to a destination are rewarded. The most successful strategies are allowed to reproduce, and the least successful strategies age and die, and are replaced by newly formed strategies.

When driving in a car, if a driver hears on the radio that the freeway is jammed, the driver selects an alternate route. This behavior in a complex adaptive system allows for optimization. Packets inbound to the wired world could route themselves over parallel routes, distributing themselves according to link congestion, thereby effectively increasing the bandwidth of the network.

If a network node fails, or moves, adaptive agents can select alternate strategies and routes to heal the network.

Complex route loop detection is a simple strategy to implement by searching the packet travel memory for duplicate nodes.

The system is comprised of programs which serve as packet agents and node agents. Packet agents determine the routing of their packet, using their internal strategy and information obtained from the node. Node agents update the routing information of the node, using information obtained from the packet agents. The agent programs and data reside in the nodes, and a small amount of data travels in the packets. (This can be limited to a small percentage of the packets, to preserve bandwidth.) The system provides for the agents to perform their strategies, then assigns them credit (fitness) based on performance. Selection of agents for reproduction is based on fitness. Reproduction introduces a random crossover and exchange of genetic strategy (the symbols which represent strategies), producing new strategies in the offspring. For example, a successful strategy "Dest1 A B C D", when mated with the strategy "Dest1 E F G H" could produce the new strategy "Dest1 A B G H". A small amount of mutation is introduced, which prevents stagnation or locking. The new strategies join the general population, as older and less fit strategies die, and the cycle continues, adapting to the environment. By changing the reward structure to favor certain strategies, those strategies quickly emerge in the majority of the population. When the opposite strategies are rewarded, they propagate similarly. The system adapts to environmental conditions under the control of the adaptive agents.

This system could be modified or extended through the introduction of new inputs from the world, and new input and output actions provided in the form of new detectors and effectors, with corresponding strategy symbols to be generated by the detector and acted upon by the effector. New inputs, and new strategy symbols, detectors, and effectors, allow the emergent

strategies to address all inputs with new behaviors in the provided effectors, creating new actions by the system. (Detectors are equivalent to the senses, effectors are equivalent to a body which receives commands and creates action.)

This invention uses concepts from the book, **Hidden Order** by John **Holland**; Addison Wesley, 1995; 185 pages; ISBN 0-201-40793-0 How Adaptation Builds Complexity.

These concepts are applied in a new way by introducing network packet agents with past history and strategy memory, and node agents with similar memory and additional memory for an array of goal based network route strategies, along with network performance credit assignment and network strategy encoding for reproduction of successful strategies, to allow reproduction with a genetic algorithm of highly fit network strategies, and to discover new network strategies. The result is a complex adaptive system which dynamically and efficiently controls and optimizes data flow through the network in a constantly changing physical network environment.

To preserve bandwidth in a bandwidth limited network, a small percentage of the packets may be used for packet agents. A specific type of packet can be used, such as routing advertisements, or a threshold can be set to send an agent packet after a specified time interval has elapsed or a specified number of packets have been transmitted.

The major part of the last two pages has been left blank for description. A suggested outline for the description is included therein. Be sure to explain the subject matter fully.

The following information is desired. Please furnish it if you can. (See instruction 2.)

A. When did the described subject matter first occur to the inventor(s)? (See instruction 3.)

9/4/2001

B. Was a drawing or sketch made and if so when? (See instruction 4.) ☒ Yes ☐ No Date 10/10/2001

C. When was the first written description of the subject matter (other than this record) made? Date 9/19/2001

Do you have a copy of it? ☒ Yes ☐ No

D. On what date was the subject matter first disclosed to others? 10/10/2001

To whom was this disclosure made? Susan Storma

Was it oral or written? Written Where was it made? Mesh Networks office

E. If this subject matter has been described orally or in writing to persons outside of the Company, or samples have been submitted to them, please state the name of such persons and the place and date.

F. Has the thing or idea that you have described in this record been tried experimentally?
Used in Company Operations?

☒ Yes ☐ No
☐ Yes ☒ No

Disclosed to or discussed with anybody outside the Company?
Sold or offered for sale?

☐ Yes ☒ No
☐ Yes ☒ No

If any answer is "Yes," state full details below where indicated. (See instruction 6.)

G. Were any funds from government grants or research contracts employed in the development of this subject matter?

☐ Yes ☒ No

DETAILED ANSWER TO ITEM F

If the thing or idea described has been tried, used or offered for sale, briefly state here the dates of such trial, where used or to whom offered or sold, and the present status.

I wrote a program to do complex adaptive routing, with strategy generation, performance of strategy, credit assignment, selection, and reproduction with crossover and mutation.

Name of persons who witnessed trial and testing of the subject matter and could, of their own knowledge, testify to what was done.

Please have two witnesses who can understand its subject matter read it and sign as indicated.

We have read this Invention Record Form and understand its subject matter this ____ day of _____, 20 ____.

Signature of Witness	Signature of Witness
Name (Please Print)	Name (Please Print)
Title	Title

DESCRIPTION OF INVENTION

(The following outline is recommended as a guide for this description. Insert extra page, if necessary.)

- I. Suggested title of invention.
- II. General description of invention.
 - A. General statement of what the invention is.
 - B. Advantages over previous practices in this field and features which distinguish the invention from prior practices.
 - C. Detailed description of the invention. The description should be adequate to provide a full understanding of the invention from this record alone. In mechanical or electrical cases, include drawings, sketches, or photographs with complete explanation, and use suitable reference numerals or letters to clarify the description. In chemical or process cases give examples in sufficient detail to enable one to carry out the invention. **If any drawings attached are prints, which are too large to conveniently pass through a standard office-photocopying machine, please supply triplicate prints for the convenience of the Patent Committee.** (If any of the drawings attached are original sketches, or prints of the first drawing of the invention. See Instruction 4.)
 - D. Variants or equivalents of the invention. What alternative approaches would work? How far can conditions and/or reactants be varied from those shown in the specific examples? This information is necessary to determine the scope of the invention.
- III. Attach original or photocopy of notebook pages where experimental data is recorded.
- IV. Closest literature (including patents) or prior work of which you are aware. Please supply copies of the literature if it is available to you.

Invention Disclosure Form Instructions

1. This record should be made out by one or more individuals, preferably the inventors, who have been intimately connected with the invention. But the purpose of the record is primarily to call attention to the new development, not necessarily to establish who the inventors are. Where several persons have made suggestions or worked on the problem, list all of them on a separate page and indicate briefly their respective contributions.
2. The purpose of this section of the record is to obtain as much preliminary information as possible. You may be able to answer these questions from your own direct knowledge or from what other people have told you. In any event, please answer them as fully as you can.
3. Give the appropriate date when the inventors first thought of this new thing or idea. This date may be of importance if an application for a patent is filed.
4. If an original sketch is available, please attach it to this record. Such sketches are valuable. Initial and date them and then send them to the Patent Committee. If the first drawing that exists is an official Company drawing and the type, which will be kept in the Company files, the original should be filed in the regular manner and three prints or other reproductions should be furnished. **Do not destroy, at any time, any original sketch, or any official Company drawing, which happens to be the first drawing of the invention.**
5. The first written description referred to is the earliest reduction of the invention to written form by you or anyone else. Attach a copy to this record, if it is available.
6. The purpose of these questions is to learn the stage of development of the new thing or idea to which this record relates. If any of the questions here stated are answered in the affirmative, give the date and such description as you think will be necessary to convey a brief but accurate picture of what has been accomplished so far in the space provided. If you have test records, drawings, blueprints or other data which you have not previously mentioned, mention them also in the detailed answer. All test records, drawings and blueprints should always be submitted in triplicate. If a model was made, tell who worked on it, and where it can be found.

General Notes

Patentable inventions are new and useful industrial processes, machines, devices, manufactured articles, compositions of matter, chemical compounds, new uses of old materials or things, and new and useful improvements of any of these – the mental conception of which was not clearly obvious, or the advantages of which were not readily predictable. **When we solve a problem in attaining some industrially useful result, the chances are good that an invention has been made.** The Company is interested in patenting any invention which may be expected to give it a competitive advantage. The Patent Committee, after receiving an Invention Record and Assignment Form, will aid the inventors in deciding what invention, if any, has been made and who made it, and will report its conclusions to the inventors.